Rapid Cadence Collections with the Space Surveillance Telescope

D. Monet
U.S. Naval Observatory Flagstaff Station
T. Axelrod, C. Claver
LSST Corporation
T. Blake
DARPA Tactical Technology Office
R. Lupton
Princeton University
E. Pearce, R. Shah, D. Woods
MIT Lincoln Laboratory

ABSTRACT

The Defense Advanced Research Projects Agency (DARPA) has constructed the 3.5-meter Space Surveillance Telescope (SST) on North Oscura Peak in the White Sands Missile Range. The primary goal of the SST program is the monitoring of the Earth's geosynchronous belt for microsatellites and debris. At the end of DARPA's demonstration period, the SST will undergo an Air Force Space Command utilization study. The DARPA press release announcing the existence of SST included the words "SST may also provide the science community a unique asset for astronomical surveys". This paper presents the preliminary results from rapid cadence science collections (1-sec integrations every 2.5-sec) of a 9.5 square degree area centered near the open cluster M67.

1. INTRODUCTION

DARPA's Space Surveillance Telescope (SST) is primarily a space surveillance asset. Figure 1 shows the facility, Figure 2 the telescope, and Figure 3 the camera. Table 1 gives a summary of its technical details. SST was designed for the space surveillance mission, but DARPA expects that SST can make available some of its time to scientific data collections. The details of how much "science" time will be available and when it can be scheduled have yet to be finalized. This study was designed to be a pathfinder for scientific access, and to capitalize on the unique capabilities of SST. The proposal requested the collection of images using a short exposure time (1.0 second) at a rapid cadence (2.5 seconds), and will search for variable stars and other astronomical phenomena that vary on short time scales. Collections were taken on 2 nights in 2012, day 089 (March 29) and 090 (March 30), and a total of 1041 frames (about 100 gigapixels) were obtained.

Fig.1. The SST facility at twilight.

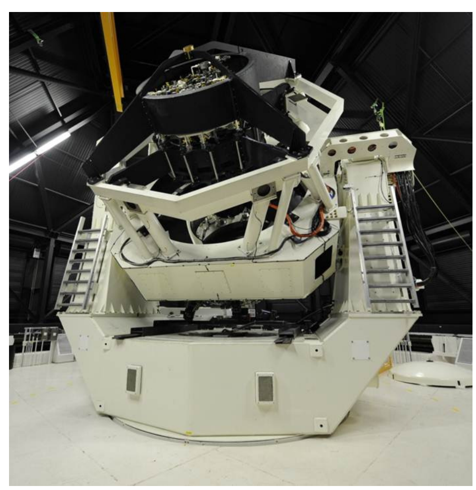

Fig. 2. The SST. The support for the secondary mirror can be seen at the top of the telescope.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2012**	2. REPORT TYPE	3. DATES COVERED **00-00-2012 to 00-00-2012**

4. TITLE AND SUBTITLE **Rapid Cadence Collections with the Space Surveillance Telescope**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Naval Observatory Flagstaff Station,Flagstaff,AZ,86001**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Presented at the 13th annual Advanced Maui Optical and Space Surveillance (AMOS) Technologies Conference on September 11-14, 2012 Maui, Hawaii

14. ABSTRACT
The Defense Advanced Research Projects Agency (DARPA) has constructed the 3.5-meter Space Surveillance Telescope (SST) on North Oscura Peak in the White Sands Missile Range. The primary goal of the SST program is the monitoring of the Earth?s geosynchronous belt for microsatellites and debris. At the end of DARPA?s demonstration period, the SST will undergo an Air Force Space Command utilization study. The DARPA press release announcing the existence of SST included the words ?SST may also provide the science community a unique asset for astronomical surveys?. This paper presents the preliminary results from rapid cadence science collections (1-sec integrations every 2.5-sec) of a 9.5 square degree area centered near the open cluster M67.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**4**	

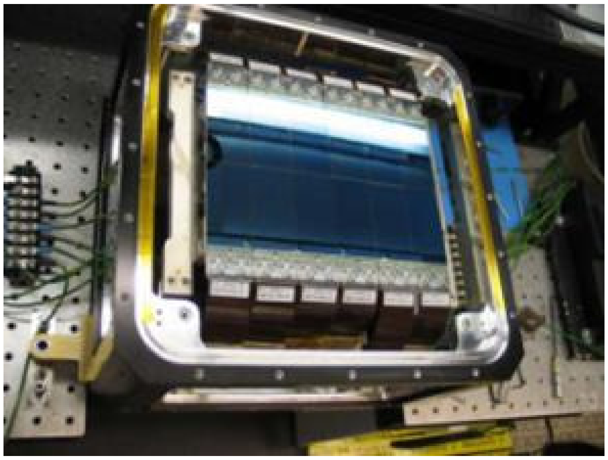

Fig. 3. The SST camera without its window.

Table 1. SST At a Glance

Telescope:
Diameter (actual): 3.50 meter
Diameter (effective): 2.90 meter
Effective focal length: 3.49 meter
Nominal field of view: 3x2 degree
Mount:
Maximum tracking rate: 4 degrees/second.
Tracking stability (jitter) maximum: 0.5 arcsec
Paint color: white[1]
Camera:
Sensors: 2Kx4K CCD (thinned, backside illuminated[1])
Pixel size: 15 microns (0.89 arcsec[1])
Mosaic: 6x2 (12288x8192 pixel effective size)
Readout time: 0.65 sec (1.30 sec this study[1])
Exposure time: 0.025 to 10 sec
Filter: clear glass (nominal 0.4 to 1.0 micron bandpass)
Image rotator: none
Mosaic alignment – long axis with telescope azimuth[1]
[1]Inferred from data in the public domain.

2. OBSERVANTIONS AND ANALYSIS

Because SST has neither a filter nor a field rotator, an exposure time of 1.0 second was selected. The nominal pointing for M67 was (8^h47^m, $+12^o08'$), and field rotation produced only minimal image smearing during the exposures. For a variety of reasons, most as yet unknown, there were various interruptions in the collections. Figure 4 shows the actual cadences.

For this preliminary analysis, the image data were used just as they came out of the camera. Bias, dark, and flat field images were taken, but several issues prevented using them without further processing. The images were processed using astrometry.net [1] and SExtractor [2]. The outputs of these two packages were merged and correlated with the USNO NOMAD catalog [3], and multiple observations of each star were collated.

Despite the rather primitive image processing, the results are encouraging. Due to field rotation, the area of sky covered by these collections is about 9.5 square degrees. In the 1041 full frames, a total of 121,973 stars had two or more measurements. Figure 5 shows the contours of the dispersion in magnitude as a function of magnitude, and Figure 6 shows a visualization of the entire error distribution. The SST mean responsivity is reasonably similar to the SDSS *r*-band, but color terms for solar type stars are about 0.1 magnitude. As expected, the median repeatability is better for bright stars, and is about 0.05 magnitudes. Our expectation is that the repeatability will improve once the bias, dark, and flat field processing is understood. Figure 7 shows the astrometric repeatability as a function of mean magnitude.

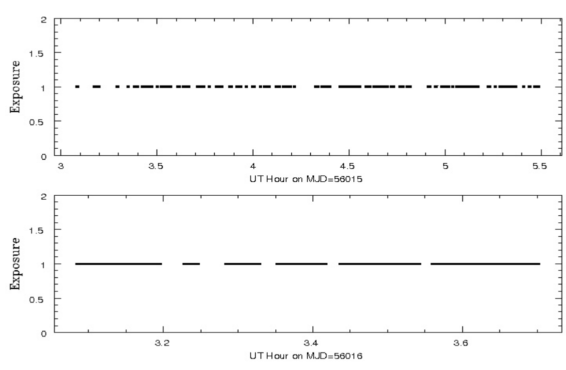

Fig. 4. Cadence of collections taken on 2012 days 089 (MJD = 56015) and 090 (MJD = 56016).

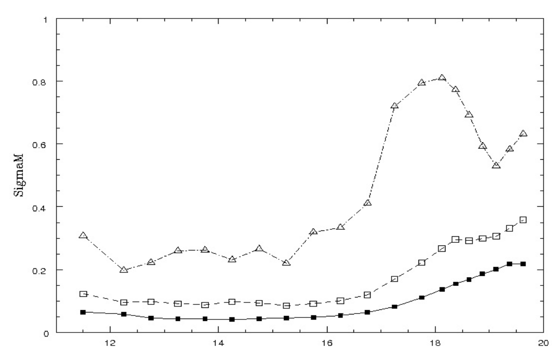

Fig. 5. 50% (■), 68% (□), and 95% (Δ) contours of the observed magnitude repeatability error as a function of mean magnitude from MJD = 56016.

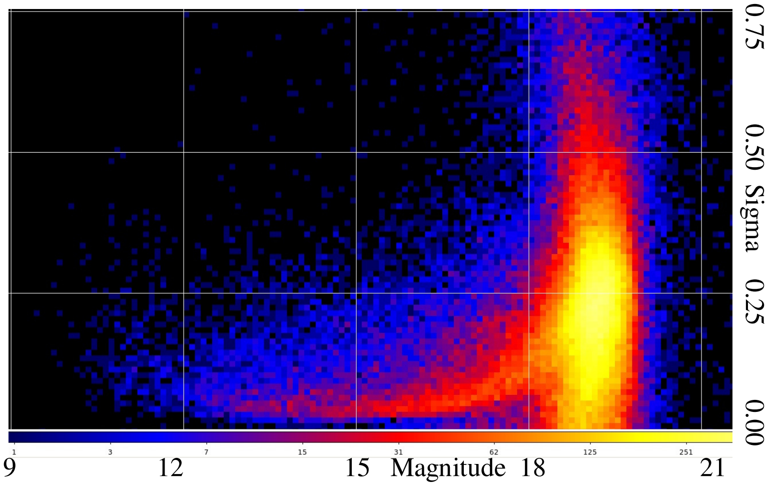

Fig. 6. Visualization of the dispersion in measured magnitude as a function of magnitude for the 121,973 stars observed more than once.

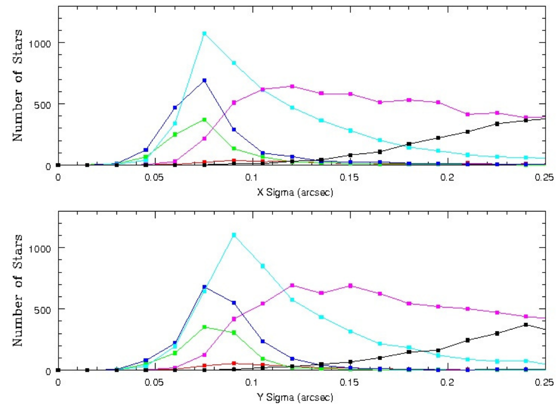

Fig. 7. Astrometric residuals as a function of mean magnitude in X (RA) and Y (Dec). Red is for mag=11, green for mag=13, blue for mag=15, cyan for mag=17, magenta for mag=18, and black for mag=19.

3. DISCUSSION

Measurements taken with the SST can probe atmospheric and astrophysical phenomena on time scales unavailable to other astronomical facilities. Discussions found in the Large Synoptic Survey Telescope (LSST) *Science Book* [4] indicate that transient events can have characteristic time scales substantially shorter than one second. With its ability to take exposures as short as 0.025 second on a cadence of about 1 second, SST can detect and study these events. Another important area for research with SST is the residual effect of atmospheric turbulence (seeing) on the astrometric properties of the image formation process when the exposure times are very short. Characterization of these effects will serve as an important pathfinder for other large aperture, rapid cadence astronomical survey facilities such as LSST and others. This study has yet to find transient events with short time scales, but the analysis of the images is far from complete.

4. ACKNOWLEDGENTS

Our sincere thanks are expressed to the members of the SST Project Team, past and present, and to the many people at DARPA and USAF who helped make this program happen. In particular, we would like to acknowledge the efforts of Richard Lambour, Michael Sanchez, and Steven Sundbeck

5. REFERENCES

1. Lang et al., http://astrometry.net.
2. Bertin et al., http://astromatic.net.
3. Monet et al, catalog http://www.nofs.navy.mil/data/FchPix.
4. Izevic et al., http://www.lsst.org/lsst/scibook.